Neural Organization of Sensor Webs

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Abstract: Sensor webs are an emerging data collection technology that is in need of an organizing schema. Artificial neural networks are a computing paradigm based on the architectures found in biological systems. Nature has been using neural networks to organize and control sensor webs for at least a billion years. This paper gives two examples of how this organization works and suggests a method to apply this established technology to the emerging technology of sensor webs.
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1 Introduction

Sensor webs (SW) are collections of pods that are dispersed over regions of interest. The webs collect data on changing spatial and temporal patterns of physical, chemical, and biological phenomena [1]. Each pod is a node in a data collection web that spans a region. The value of sensor pods comes from the fact that they are in the environment and can sense data that is inaccessible to long range sensors.

This exciting new technology could, however, be enhanced by the use of more sophisticated organizing techniques. Current SW interconnection models consist of all-to-one connections or series connections like those used for Christmas tree lights. Fortunately, nature provides us with some excellent models of organization. One of nature's most successful organizing techniques is the neural network.

Artificial Neural Networks (ANN) are an organization and information processing technology inspired by nature. Large numbers of simple processing units are organized in a variety of ways to solve an even larger variety of problems [2]. In nature the basic processing elements are neurons. In the ANN community, the processing elements are software functions and Application Specific Integrated Circuits (ASIC). When sensor webs are organized as neural architectures, the processing units will be the sensor pods.

This paper describes two examples of neural network architectures that might be used to organize sensor webs. In each case we will first describe the topology and functionality of the neural network architecture. Then we will show how this architecture might be applied to the organization of sensor webs.

The first example describes a technique that nature uses to organize information coming from the eyes, ears, and tactile sensors. This technique allows organisms to detect edges (sudden changes in phenomena). The second example illustrates neurons used for motion detection (phenomena translation).

Some interesting features of biological and artificial neural networks (not explored in this paper) are fault tolerance, graceful degradation (the ability to function when damaged), and the ability to learn. These are some of the many advantages that could be brought to the emerging field of sensor webs through the adoption of neural architectures.

2 Center-surround neural nets

The center-surround architecture is found when neurons are arranged in one-layer sheets, and each neuron is connected only to its immediate neighbors. In nature this architecture occurs in many places, most notably in the retina of the eye [3]. In artificial neural networks, this architecture is most often found in Cellular Neural Networks (CNN). In both cases, the basic functional topology is the same: the neural sheet is exposed to some input and each neuron is prevented from firing by the inhibiting effects of approximately half of its neighbors. Figure 1a shows a single neuron (or sensor) with center-surround connections.

One of the many phenomena that are detectable with center-surround architectures is the movement of edges across a receptive field. In the retina the edges of objects in the visual field are detected in this way [4]. In Figure 1a, the edge of a shadow is moving across the receptive field of a center-surround neuron. All the neighbors of this neuron have an inhibiting effect. In this example the degree of excitation of the central neuron must be approximately 4.5 times the inhibition caused by a single neighbor. If there is no edge to occlude any part of the receptive field, the level of excitation will be 4.5, but the level of inhibition will be 8 (one for each neighbor). Hence the neuron is not normally active.

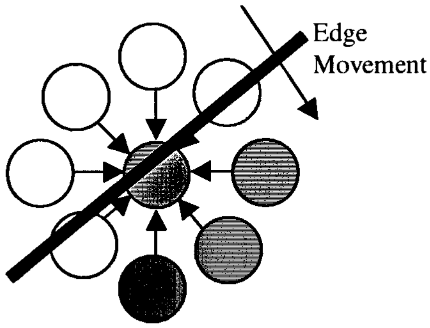

Figure 1a: A center-surround neuron is firing because it is stimulated by an outside source and it is only being inhibited by three of the surrounding neurons. Earlier in the edge movement, the center neuron was not firing because it was inhibited by more than four surrounding neurons. Later in the edge movement the center neuron will not be firing because the moving edge will occlude outside stimulation.

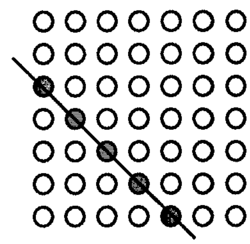

Figure 1b: An array of center surround neurons. The neurons along the moving edge are firing but they are the only ones that are firing. Neurons on one side of the moving edge are occluded from the external stimulus and neurons on the other side of the moving edge are surrounded by too many inhibiting neural neighbors.

Figure 1: Center Surround Architecture

2.1 Center-surround sensor webs

Center surround sensor webs can detect a wide variety of 'edges.' One set of examples is those connected with atmospheric phenomena such as isobars and thermoclines. Center-surround sensor webs like the one in Figure 1b can detect edges that represent abrupt changes in whatever quantities are being sensed.

A center-surround web of weather sensing pods spread in a uniform grid across a region of the surface of Mars could instantly draw the lines seen on weather maps. Lines of equal barometric pressure (indicating highs and lows) and lines of equal temperatures could be continuously updated with such a sensor web. Other applications include detecting: the spread of radiation or chemical toxicity, the spread of seismic activity, the spread of a traffic jam over a sensor web that spans a city, and the movements of an intruder against a background of ambient starlight.

3 Motion detection by neural nets

There are many more light sensors in the retina than there are fibers in the optic nerve connecting the retina to the brain. Consequently, the information that the eye sends to the brain must be compressed. One of the ways that the data is compressed is through the use of motion detectors [5]. A variety of sensors are connected to one neuron but the delay time of the transmission from each sensor is staggered. The staggering of delays is such that if an object is moving across the field of vision at exactly the right speed and direction, all the stimuli arrive at the neuron at exactly the same time and the neuron's firing threshold is exceeded.

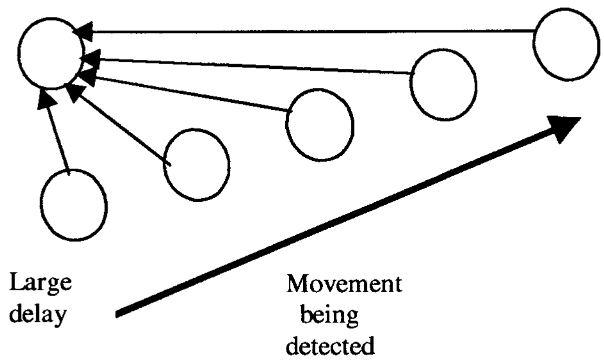

Figure 2a: When a single neuron receives inputs from a row of sensors and the delays in transmission times between sensor and neuron are sequential, a moving target can stimulate the sensors at exactly the right times so that the progressively delayed signals arrive at the neuron simultaneously, causing the neuron to fire.

Figure 2b: By carefully choosing delay times for a cluster of sensors, and distinguishing between peripheral sensors and interior sensors, it is possible to record the direction and speed of observed phenomena. In the example at the right, two sensor pods are active because these two pods are exactly the right distance apart to provide the right activation delays. The distance between the active pods provides an estimation of the speed of the moving target and the relative positions of the active pods indicate the direction of target movement. The peripheral pods always mark the exit of the target. There are two sets of inter-pod signals being evaluated: from peripheral to interior and from interior to peripheral.

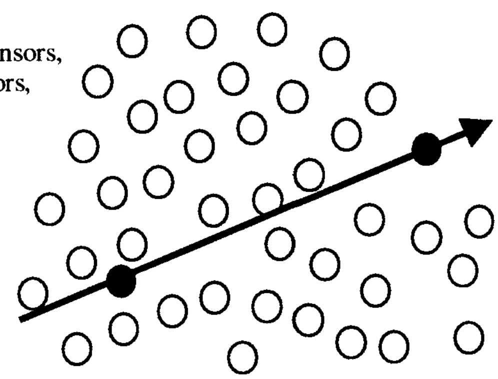

Figure 2: Motion Detection Architecture

3.1 Motion detection by SW

Motion detection networks (see Figure 2) can be used to detect the movement of perceived objects over the receptive field of the sensors. Detecting this movement is especially easy if the direction and speed of the movement is known (Figure 2a), as would be the case with natural and artificial satellites. Detection of movements which have unanticipated directions and velocities, such as monitoring aircraft movements, would be possible with a circular web of sensors (Figure 1b).

4 Conclusion

These are only a few of the many ways that neural network architectures can be used to organize and control sensor webs. The two examples given here were selected from hundreds of obvious examples. Some of the more interesting but omitted examples include networks that learn, Independent Component Analysis (ICA) networks, autoassociative networks [6], and Kohonen networks (self-organizing maps).

Self-organizing maps refer to the ability of neural networks to find a correlation between data points without the benefit of training or a teacher. It also is the way that the points on the retina map to corresponding points in the visual area of the occipital lobe of the brain; and the way that the spinal nerves leaving the brain go to the correct fingers, toes, and other parts of the body. This mapping is complete before the organism opens its eyes the first time.

5 Acknowledgment

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6 References

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